ECONOMIC FEASBILITY OF INSTALLING AN ANAEROBIC DIGESTER ON

A DEPARTMENT OF DEFENSE INSTALLATION

THESIS

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AFIT/GES/ENV/10-M05

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THESIS

Presented to the Faculty

Department of Systems and Engineering Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Environmental Engineering and Science
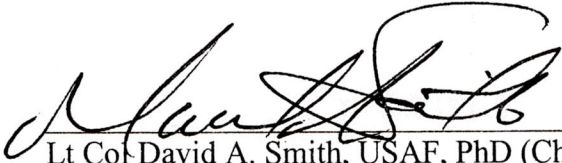
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March 2010

AFIT/GES/ENV/10-M05

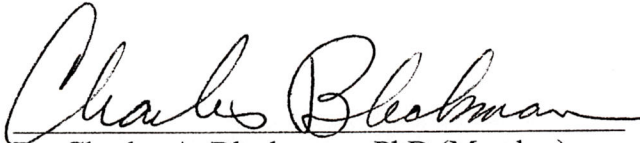ECONOMIC FEASIBILITY OF INSTALLING AN ANAEROBIC DIGESTER ON A
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Approved:

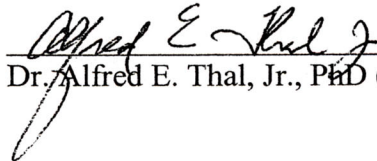_____   _12 MAR 2010_
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AFIT/GES/ENV/10-M05

Abstract

Improving technology has made anaerobic digestion a viable method for disposing of organic waste and creating alternative energy. The purpose of this research was to examine the feasibility of installing an anaerobic digester on a Department of Defense installation, and measure its contribution to the execution of Executive Order 13423. A present worth equation was derived in accordance with 10 Code of Federal Regulations 436 expressing viable costs and benefits of an anaerobic digester. A case study of Wright Patterson Air Force Base (WPAFB) was then presented using the derived equation and operational data from functional digesters in the Ohio area. The research identified that an anaerobic digester at WPAFB is not financially practical at this time, but would contribute towards the goals of Executive Order 13423. The derived cost-analysis equation can be applied to any U.S. military base.

To STOPLIGHT, for inspiring me to go back to school

Acknowledgements

I would like to express sincere appreciation to my research advisor, LtCol David A. Smith, for his guidance and support throughout the course of this thesis effort. I would also like to thank Jim Currie and Clemens Halene at the co-op of the Ohio State Agricultural Research and Development Center and Quasar Energy Group in Wooster, OH for their continued support, knowledge, and assistance with technology for anaerobic digestion. My parents also deserve credit for supporting me throughout this graduate program, as well as the past thirty years.

Russell A. Strange

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I. Introduction

1.0 Background

Executive Order (E.O.) 13423, "Strengthening Federal Environmental, Energy, and

Transportation Management," January 24, 2007 is the current, and most stringent, policy

directing all federal agencies, including the Department of Defense (DoD), towards a

more environmentally-friendly and sustainable-state of energy consumption. There is no

single solution for the DoD to utilize in fulfilling the order's requirements. On the

contrary, the order will be carried-out through a combination of policy changes,

behavioral changes, procedural changes, infrastructure improvements, and the

incorporation of new technology. Anaerobic digestion used for the production and

capture of biogas is a developing field of study that can contribute to meeting the

demands of E.O. 13423, specifically goals (a)-(e) of Sec. 2.

Anaerobic digestion is the consumption of organic material by bacteria in the

absence of oxygen. The resulting products of this process are biogas and organic

effluent. Biogas is primarily methane and carbon dioxide. The effluent is a nutrient-rich solid similar to compost. Biogas can be burned as a gas in its normal state, or compressed into a liquid fuel very similar to natural gas. Biogas can be used as a heating fuel, or used to fuel a compression-ignition or spark-ignition engine. Such an engine can be combined with a generator to create electricity. In turn, anaerobic digestion is a renewable source of energy as it can be fueled by almost any kind of sustainable biomass (Oregon, 2010).

Controlling the process of anaerobic digestion occurs in man-made structures called anaerobic digesters. Digesters can come in many forms with various mechanisms, but they are all designed to foster the production and capture of biogas. Several farms and wastewater treatment plants across the United States are now utilizing an anaerobic digester to treat, and harness energy from, the organic waste of animals and humans. This research will focus on the potential of installing an anaerobic digester on a military base to contribute towards the demands of E.O. 13423 (U.S. EPA, 2010).

1.1 Research Objectives

Although 10 CFR 436 provides Federal agencies with general guidance on how to perform a cost-analysis, specific instruction on how to analyze various technologies is lacking. So in conjunction with the demands of E.O. 13423 and the lack of technology-specific guidance, the main objective of this research is to develop a methodology for examining the economic feasibility of installing an anaerobic digester on a U.S. military base. Any base commander wishing to examine the potential of installing a digester on his or her base could then use this methodology. Wright Patterson Air Force Base

(WPAFB) will be used as an example throughout this project; however, the intent is for the methodology to be adaptable to any base wishing to capitalize on the benefits of an anaerobic digester. Because the focus of this research is the cost-analysis of installing a digester, a very real possibility exists that a digester is found to not be economically feasible. This research will also attempt to examine whether a potential digester that is found not to be economically feasible should still be installed in order to help meet the requirements of E.O. 13423.

1.2 Methodology

This approach will lead to a methodology that any base command can use to analyze the potential of anaerobic digestion on its installation. The study begins by establishing background information on the base to be analyzed. More specifically, information will be collected on the base's population, tenants' activities, wastewater output, wastewater composition, wastewater treatment costs, electricity consumption, and electricity costs.

The next step will be examining the cost of installing an anaerobic digester and generator. Contractors and/or agencies that have recently installed a digester will be used to estimate the cost of installing a digester, based on the background information found in the previous step. Local information will also be required to predict operating and maintenance costs of the installed digester. The economic projections of maintenance costs, operating costs, sewage costs, electricity costs, and inflation will be modeled from historical data and trends. The maintenance and operating costs will be projected from data of established digesters in the vicinity of WPAFB (Dayton, OH Wastewater

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Treatment Plant (WWTP), Akron, OH WWTP, and the Ohio State Agricultural Research and Development Center (OARDC)). These findings will be combined to create a total cost picture of installing and operating a digester.

Continuing on, the energy potential of a base's waste stream will be determined. Founded on the waste output, waste composition, and projected performance of the installed digester/generator, a base's energy potential will be expressed in kilowatts per year (kW/yr). As a result of a base producing X kW/yr of electricity, this thesis will assert that the base no longer needs to purchase X kW/yr of electricity from the local power company. Based on the current cost for electricity from the power company to the base, X kW/yr will translate into a dollar amount the base no longer must spend on electricity. X kW/yr will also be translated into tons of green house gas (GHG) no longer being emitted due to that amount of electricity no longer coming from a coal-fueled power plant. Another addition to less GHG being emitted due to the base is the amount of methane captured in the digester; otherwise this gas would have been emitted into the atmosphere as the waste stream traveled to the local wastewater treatment plant.

As a result of using the biomass in the base's waste stream to feed the digester, the sewage output to the local wastewater treatment plant will decrease. This decrease in the annual output of wastewater going to the local treatment plant will then be translated into savings based on the current cost the plant charges for treating a gallon of wastewater. The savings from electricity and sewage treatment will be combined and viewed as an annual amount contributing to the capital recovery of the digester.

The determined costs of installation, operation, and maintenance will then be analyzed against the determined savings from the digester. These values will then be projected into the future using appropriate engineering economic methods. Based on these projections, one potential result will show the digester paying for itself over time through electric and wastewater savings. Another possibility is that the cost of installing, operating, and maintaining the digester will never be recovered from the savings. If this is the case, a further analysis will be performed to determine how much better the digester/generator would have to perform in order to be economically feasible. In other words, how many kW/yr would a digester/generator have to produce per gallon of wastewater in order to recover its capital cost in a reasonable amount of time? Regardless of whether a digester is found to be feasible or not, its contribution to a base's fulfillment of E.O. 13423 will be analyzed.

1.3 Scope And Limitations

This study is based upon a continuously and uniformly operating digester/generator using a continuous waste stream with a constant composition. Reality dictates that any infrastructure and machinery will occasionally be shut down for maintenance and unplanned failures. Stoppages in the production of electricity can only be speculated upon from the operational experience of digesters/generators in locations other than WPAFB. Waste streams will fluctuate over time for reasons such as work schedules, seasons, weather, base activities, etc., but will be considered constant for the purposes of this study.

This study will assert that all electricity created from the digester can be used on base, an absolute replacement for that portion of electricity no longer purchased from a local power company. A portion of the electricity created by the generator will be recycled to run the digester in order for the system to be self-sustaining. The performance of the projected digester/generator may not exactly mirror the performance of a digester installed at the study location in the future due to changing technology, installation issues, infrastructure considerations, and budget influences.

The data used for waste stream energy potential from WPAFB will come from a previous study of the composition of the WPAFB wastewater. A proper analysis of WPAFB's wastewater would take 12 months in order to incorporate the influences of weather and seasonal changes. A year of waste analysis was outside the scope of this study.

II. Literature Review

2.0 Background

The review of literature for this study consists of three primary categories: legislation, the basics of anaerobic digestion, and the application of anaerobic digestion to harness energy. The legislation discussion will cover current laws and orders concerning new and improved sources of energy in order to improve the U.S.'s energy security, decrease dependence on foreign fuels, and decrease GHG emissions that could lead to global climate change. The basics of anaerobic digestion will focus on microbiology. The application discussion will show the progression of digesters from rural backyards in developing countries, to highly advanced units operating today in the U.S.

2.1 Air Force Policy Directive 23-3, September 7, 1993

Although written on September 7, 1993, Air Force Policy Directive (AFPD) 23-3 still stands as a pillar in the Air Force energy management program. The directive begins with a list of bulleted statements concerning energy use in the Air Force that still apply today. A few of the significant items related to this study include the simple fact that the Air Force consumes a significant amount of energy in support of national defense, as well as spending a significant amount of money to acquire this energy. The Air Force must establish policies to responsibly allocate, control, and use this energy in the face of limited energy reserves, restrictive budgets, and potential pollution of the environment. The Air Force also will use efficient and cost-effective technology to eliminate waste and conserve energy resources. Capital investment and improved operations will be used to

increase utility energy efficiency. The directive also points out the importance of

recognizing achievements of individuals and organizations in the fields of conserving

aircraft, utility, and vehicle energy, furthering national energy policy, and obtaining

monetary savings.   As a direct result of the directive, each level of command in the Air

Force (HQ USAF, MAJCOM or equivalent, or installation) was required to form an

Energy Management Steering Group (EMSG) to oversee all energy matters concerning

the applicable orders to their command. In turn, each base has an EMSG that could

benefit from analyzing the potential of installing and operating an anaerobic digester.

2.2 Energy Policy Act of 2005

The Energy Policy Act of 2005 (EPAct 2005) became law on August 8, 2005.

The bill was a long-overdue overhaul of its 1992 predecessor. Rising energy prices and

dependence on foreign fuels spurred the passing of this law, which created several tax

breaks and incentives for domestic energy production. An entire title of the bill, Title II,

is devoted solely to renewable energy. Section 202 of Title II expands the timeframe and

eligible participants of the Renewable Energy Production Incentive (REPI). The REPI

appropriates funds to any qualifying project built from the time of the bill through 2026.

A qualifying facility is one that produces and sells renewable energy, to include: not-for-

profit electrical cooperatives, public utilities, state governments, commonwealths,

territories of the United States, Indian tribal governments, and Native Corporations that

sell the facility's electricity. The REPI pays a qualifying facility $.015 per kWh (1993

dollars and indexed for inflation) produced for the first 10 years of operation (US DoE,

2009). Because appropriations are currently established until 2026, a facility would need

to be built by 2016 in order to receive the full 10-year benefit of the REPI. Sec. 202

enables the REPI to now include facilities using landfill gas, livestock methane, and ocean energy. Being that landfill gas is another name for biogas, an anaerobic digester project would now qualify for a REPI.

Section 203, Federal Purchase Requirement, requires federal agencies to purchase power from renewable sources to the extent of being economically feasible and technically practicable. For FY2007, the requirement for federal use of renewable energy, in comparison to total federal electric energy use, was 3.0%. This number rises to 5.0% for FY2010 and 7.5% for FY2013. An important note on these numbers is any renewable energy produced at a federal site, on federal land, is eligible for double credit. In turn, any electricity created by an anaerobic digester on a DoD base would count twofold towards the requirements (Holt and Glover, 2006).

2.3 Executive Order 13423

Executive Order 13423 was signed into law on January 24, 2007 by then President, George W. Bush, with the goal of strengthening Federal agencies' environmental, energy, and transportation management. The policy of the order, Section 1, is very direct:

> *It is the policy of the United States that Federal agencies conduct their environmental, transportation, and energy-related activities under the law in support of their respective missions in an environmentally, economically and fiscally sound, integrated, continuously improving, efficient, and sustainable manner.*

Section 2 of the order details the specific goals for the agencies. Goal (a) demands a reduction of energy intensity by either 3% annually through the end of fiscal year 2015 or 30% by the end of fiscal year 2015, with the baseline being the agency's

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energy use in fiscal year 2003. Improving energy efficiency and/or reducing GHG

emissions will accomplish a reduction of energy intensity. Anaerobic digestion can

contribute in both of these aspects of reducing energy intensity. Goal (b) is to ensure that

at least half of the agency's required, renewable energy consumption comes from new,

renewable sources. Goal (b) also encourages agencies to implement renewable energy

generation projects on agency grounds, for agency energy consumption. An anaerobic

digester installed on base is an excellent example of such a project. Goal (c) focuses on

reducing water consumption intensity. Agencies are to use life-cycle, cost-effective

measures to reduce water consumption by 2% annually through the end of fiscal year

2015 or by 16% by the end of fiscal year 2015, with the agency's water consumption in

fiscal year 2007 as the baseline. An anaerobic digester could help reduce the amount of

wastewater a base discharges, thus reducing water consumption intensity. Goal (d)

requires agencies to use biobased, environmentally preferable, energy-efficient, water-

efficient, and recycled-content products in its acquisitions of goods and services. The

solid effluent from an anaerobic digester is fertile compost, meeting the above

requirements, which could be used on base for landscaping and aesthetic purposes. An

anaerobic digester would directly contribute to achieving goal (e), which calls for an

increased diversion of solid waste as appropriate (Bush, 2007).

2.4 Instructions for Implementing EO 13423: Strengthening Federal Environmental, Energy, and Transportation Management

Per the authority granted under Section 4(b) of the E.O., the Chairman of the

Council on Environmental Quality (CEQ) issued instructions to define agency

requirements and offer general guidance to fulfill these requirements. Section I. D. of the

instructions provides overarching directives for the agencies to follow, including using

environmental management systems (EMS), complying with all environmental and

energy legal and regulatory requirements, and analyzing life-cycle costs of all future

investments and procurements. All of these apply to the installation of an anaerobic

digester. An EMS is defined as "a tool used to pursue polices and goals established by an

organization by properly managing its operations and activities." Because the E.O.

orders each agency to create EMSs at all appropriate organizational levels, each base

will, or should have, an EMS. In turn, the installation of an anaerobic digester should,

and most likely will, be coordinated by a base's EMS in order to coordinate all of a

base's sustainable practices related to environmental and energy-related activities. The

applicability of the environmental compliance section to a digester is the obvious

interaction with wastewater. Although an anaerobic digester can be a sustainable,

renewable energy source, state and federal compliance regulations will be directly

applicable to the biomass being used. In turn, the costs of regulation compliance will

need to be included in a cost-analysis of installing a digester. This leads directly into the

guidance of performing a life-cycle cost and savings assessment of all future projects and

procurements. The instructions later direct users to 10 Code of Federal Regulations

(CFR) 436, Subpart A. for specific guidance on measuring life-cycle costs. This thesis

will attempt to supplement these instructions by providing a financial assessment method

specifically for anaerobic digesters. Section VI. Energy and Water Management,

discusses funding possibilities for sustainable projects. More specifically, the

instructions promote the combination of appropriated funds with Energy Savings

Performance Contracts (ESPCs). In other words, a base command can acquire specific

funding for sustainable projects, along with using its normal budget resources. The

instructions also direct that any appropriated, but unused, funds due to energy savings

may be used for other sustainable projects. A specific instruction for all agencies is to

"purchase electricity and thermal energy from sources that use high efficiency and low-

carbon generating technologies." An anaerobic digester is clearly a tool agencies could

use to follow this order. Section VII. Acquisition and Green Product Designations

designates the creation of a Federal Green Purchasing Program in which each agency

shall give preference to the purchase of energy from renewable sources. An anaerobic

digester on base would provide the extra benefit of a base not having to pay for the

renewable energy from its own digester.

2.5 10 CFR 436

Part 436, Federal Energy Management and Planning Programs, of chapter 10 of

the CFR provides guidance from the DoE on how to perform life cycle cost analyses of

potential investments in building new energy systems and conservation measures. The

methodology defined in part 436.12 is an analysis of relevant costs over the relevant life

of a project, relating initial costs to future costs by the technique of discounting future

costs to present values, also known as engineering economics. Part 436.14 presents

methodological assumptions for life cycle cost analyses that will be applied to the

methodology of this research:

1. Future cash flows will be established in current dollars, consistent with the nominal or

real discount rate published in the annual supplement to the Life Cycle Costing Manual

for the Federal Energy Management Program. The nominal rate shall be a 12-month

average of the composite yields of all outstanding U.S. Treasury bonds neither due nor

callable in less than 10 years. This rate shall be updated and reported by the Federal

Reserve Board. The real discount rate shall be between 3%-10% and be a 12-month

average of the composite yields of all outstanding U.S. Treasury bonds neither due nor

callable in less than 10 years as reported by the Federal Reserve Board, minus the

estimated increases in price levels as projected inflation in the latest Economic Report of

the President's Council of Economic Advisors.

2. Energy prices will change at rates projected by DoE's Energy Information

Administration and published by NIST annually in the Annual Supplement to the Life

Cycle Costing Manual for the Federal Energy Management Program, in tables consistent

with the discount rate determined by DOE by the process listed in the first assumption.

3. The price of energy in the base year is the actual price charged for energy and may be

provided by the energy supplier.

4. The life cycle costs shall be evaluated over the expected life of the project, or 25

years, whichever is shorter.

5. The expected life of a project is that period of service of the project without a major

renewal or overhaul, as estimated by an appropriate expert.

6. Investment costs are a lump sum occurring at the beginning of the base year.

7. Operation and maintenance costs begin to accrue at the beginning of the base year or

when projected to actually occur.

8. All costs incurred during a given year may be viewed as a lump sum at the beginning

of that year.

Part 436.16 establishes the relevant costs associated with a new energy project as

investment costs, operation and maintenance costs, replacement costs, and salvage value.

The present value of any recurring costs will be determined by multiplying the value of

the recurring cost by the appropriate uniform present worth factor as determined by the

discount rate determined above. The present value of any non-recurring costs will be the

product of those costs by the appropriate single present worth factor for the respective

years those costs will be incurred. Part 436.17 describes how to establish energy costs by

multiplying the total units of energy used in the base year by the price per unit of energy

in the base year, as determined in part 436.14. This cost will then be used to project

future energy costs by multiplying the base year cost by the appropriate uniform present

worth factor, adjusted for the escalation rates determined previously, applicable region,

and study period determined previously. Part 436.18 explains how to measure cost-

effectiveness. After performing the calculations described above, a new project is

deemed cost-effective if the life cycle cost is lower than the current system, net savings

are positive, the savings-to-investment ratio is estimated to be greater than one, or the

adjusted internal rate of return is estimated to be greater than the discount rate as set by

DOE. The life cycle cost is defined as the sum of the present values of investment costs,

operation and maintenance costs, replacement costs, and energy costs minus salvage

values of replaced items and salvage value of the system at the end of the study period.

Part 436.24 allows for uncertainty analyses for variables not defined by the code.

Sensitivity and probability analyses may be performed on variables not defined in the

code using standard engineering economics methods (10 CFR 436, 2004).

2.6 Air Force Policy Memorandum 10-1.1, "Air Force Energy Program Policy Memorandum"

The U.S. Air Force is currently setting the example for the other services in the

DoD in regards to energy policy for the future, as evident in the Air Force Energy Program Policy Memorandum, AFPM 10-1.1, of June 16, 2009. AFPM 10-1.1 is the most current and stringent energy policy in the DOD; the memorandum is an overview of forthcoming Air Force Policy Documents and Instructions. Several important points stand out in the Background section of the memorandum. The driving guidance for this memorandum is credited to the Air Force Policy Directive (AFPD) 23-3, "Energy Management," the EPAct of 2005, and EO 13423. In FY 2007, energy costs for the Air Force exceeded $6.9 billion, of which, facility energy accounted for $1.1 billion. Energy security has assumed a vital role in the future of national security. Air Force environmental goals are categorized into two main categories: green procurement and GHG. Green procurement is the acquisition of environmentally preferable services and products, in accordance with Federally-mandated procurement programs, with the purpose of enhancing and sustaining mission readiness, reducing resource consumption, and reducing waste generation. GHG goals focus on evaluating and developing protocols to identify, quantify, and manage GHG emissions, as well as an overall reduction of GHG emissions from Air Force operations.

Section 3 of the memorandum, Air Force Energy Strategic Plan, provides the purpose, vision, and strategy of the future of energy consumption in the Air Force. The purpose of the plan, as a component of the overarching, service-wide priorities of the Air Force, is to meet or exceed all goals of Federal law and EOs in regards to energy. The Air Force Energy Initiative's vision is "Make Energy a Consideration in All We Do." Air Force energy goals will be met only by involving everyone in the Air Force. The Air Force Energy Strategy consists of three components: reduce demand, increase supply,

and culture change. Anaerobic digesters can be directly applied to the second component of increasing supply, which the memorandum defines as the creation of new domestic supply sources by researching, testing, and certifying renewable, alternative, and traditional energy sources.

Increasing supply is further expanded with an overarching goal of committing the Air Force to increasing the amount of energy supplies available to become more energy independent. Energy independence is directly related to the reduction of energy required from foreign sources. When possible, the Air Force will reduce GHG emissions by using renewable energy sources. These goals are directed at the areas of aviation fuel, ground fuel, and installation energy. Implementation Goals are provided to increase energy supply, one of which is to increase facility renewable energy use at annual targets of 5% by FY10, 7.5% by FY13, and 25% by FY25. New, renewable sources must contribute at least 50% of these increases. The Overarching Objectives of increasing supply are to increase alternative fuels, increase renewable energy, utilize public-private partnerships, and enhance energy security. Implementation Objectives that could benefit from anaerobic digesters include developing renewable energy resources on base and identifying/developing privately financed/operated energy production on Air Bases. The Metric pertaining to installation energy requirements will be the overall percentage of alternative/renewable fuels used on base. Anaerobic digestion of sewage and other biomass would count as alternative energy.

Section 4 of the memorandum defines the Roles and Responsibilities of all involved, from the service's top leaders down to individual support organizations. Within the chain of parties involved, installations are given specific direction. Each

installation in the Air Force is required to develop plans to support their Major

Command's energy management programs in accordance with AFPD 23-3. A strong

example of an installation supporting this guidance would be the installation and

utilization of an anaerobic digester.

The appendices of the memorandum specify working groups to be formed to

implement the above-mentioned orders. One of these is the Infrastructure Working

Group, which will provide policy, resources, advocacy, and oversight of infrastructure

energy programs to meet or exceed the mandates of EPAct of 2005, EO 13423, and other

Federal and DoD mandates. A specific objective of this group is to develop on-base

renewable energy resources where life-cycle cost-effective. This research will contribute

towards determining the cost-effectiveness of anaerobic digesters, and in turn, the

contribution of anaerobic digesters to the implementation of the guiding orders (SECAF,

2009).

2.7 Energy Independence and Security Act of 2007

The majority of this act is focused on increasing energy efficiency and the

availability of renewable energy throughout the U.S. The first three titles of the bill are

Energy Security Through Improved Vehicle Fuel Economy, Energy Security Through

Increased Production of Biofuels, and Energy Savings Through Improved Standards for

Appliances and Lighting. Subtitle D, Industrial Energy Efficiency of Title IV: Energy

Savings in Buildings and Industry may be influenced by the use of an aerobic digester.

Although the focus of this subtitle is for major industrial and large commercial

combustion sources in the U.S., military bases could be included in the recoverable waste

energy inventory program run by the EPA, as directed by Section 452. Subtitle B, Energy Savings Performance Contracting of Title V: Energy Savings in Government and Public Institutions includes several sections that can be related to anaerobic digesters. Sections 511 and 512 help improve the contracting and funding of energy saving projects using Energy Savings Performance Contracts (ESPCs). Section 515 expands the government's definition of energy savings reduction to include increased use of an existing energy source by cogeneration or heat recovery, use of excess electrical or thermal energy generated from onsite renewable sources or cogeneration, and increased energy-efficient use of water resources. Anaerobic digesters obviously are encompassed in this definition. Section 516 permits federal agencies to retain all energy and water cost savings obtained from utility incentive programs, which could include harnessing energy from an anaerobic digester. Section 517 directly addresses the DOD and the Department of Energy (DOE) to study the use of ESPCs in non-building applications, which includes vehicles and federally owned equipment to generate electricity or transport water. Anaerobic digesters and generators would qualify as federally owned equipment that generates electricity. Section 527 of Title V's Subtitle C, Energy Efficiency in Federal Agencies orders all federal agencies to issue an annual report on initiatives to improve energy efficiency, reduce energy costs, and reduce GHG emissions. An anaerobic digester would contribute to all of these initiatives. Title X: Green Jobs authorizes up to $125 million in funding to establish national and state job training programs to address job shortages that are impairing growth in green industries such as energy efficient construction, renewable electric power, and biofuels development. This money could be used to train anaerobic digester operators and maintainers.

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Perhaps the most significant section of this act pertaining to installing an anaerobic digester, or at least studying the feasibility of installing one, is Section 803 of Title VIII: Improved Management of Energy Policy. This section provides for a 50% matching grant program for the construction of small, renewable energy projects that will create less than 15 megawatts. In essence, this grant would cut in half the cost for a base to install an anaerobic digester. Section 806 states a national goal to use renewable energy resources from agricultural, forestry, and working lands to contribute at least 25% of the nation's energy use by 2025. The use of agricultural waste and biomass in anaerobic digesters would contribute to reaching this goal (Sissine, 2007).

2.8 Anaerobic Digestion And Biogas

Anaerobic digestion is the decomposition of organic material by bacteria in the absence of oxygen. There are four types of bacteria that work together in anaerobic digestion to create biogas. The process begins with complex organic wastes being broken down into sugars and amino acids by hydrolytic bacteria. This process is called hydrolysis, or liquefaction. The sugars and amino acids are then converted into organic acids by fermentative bacteria. Acidogenic bacteria convert the organic acids into acetate, carbon dioxide, and hydrogen. Ultimately, methanogenic bacteria create biogas with acetic acid, carbon dioxide, and hydrogen. The resulting biogas is typically 60-80% methane, 20-39% carbon dioxide, and 1% mix of other gases. This process occurs naturally in swamps, in the confines of landfills, and in controlled environments called digesters (Oregon, 2010).

2.9 Anaerobic Digester Design

Initial design of an anaerobic digester begins with the type of digester to be used. The three primary designs are covered lagoon digesters, complete-mix digesters, and plug-flow digesters. Of the three, covered lagoons are the simplest in design and cheapest in construction. Most lagoons are nothing more than a pond or pool with an airtight cover. Covers can be firm to help direct the flow of biogas, or they can be flexible in order to expand as biogas volume increases. More advanced lagoons may have a mixing mechanism, but this apparatus leads the digester into the second type of design. Due to the simplicity of a lagoon, and the inherent methane emission of livestock manure, most lagoon digesters will be found in agricultural environments. Complete-mix digesters use various mechanisms to continually stir a batch of waste. The constant mixing permits anaerobic bacteria and enzymes to affect more waste than a lagoon does, as well as preventing a film or layer of scum forming on top of the waste as can be witnessed in a lagoon. Due to the mixing mechanism's capital and operating costs, they are almost always more expensive than lagoons. The primary difference of plug-flow digesters is the concept of passing waste through as if on a conveyor belt rather than digesting one batch at a time. In concept, a plug-flow digester can incorporate a constant stream of waste since the digestion occurs over time and the distance traveled within the system. These designs also relate to the typical amount of solids in the waste stream. A covered lagoon is generally used for liquid manure containing 2% or less solid material. A complete-mix digester can handle 2-10% solids. Plug-flow digesters can go up to 13% solids. As the percentage of solids in a waste stream increases, the ability of that waste to flow decreases. This leads to an inherent hurdle of digesting MSW, which is typically

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non-fluid. The basic answer to this problem is to dilute MSW with water, sewage, and/or sludge, all of which create a slurry that can flow through pipes and pumps. Current research points to a slurry needing to be diluted to about 10% total solids to flow through a digester properly (Igoni *et al.*, 2008).

The mixing of organic material in a digester, and not necessarily just in a complete-mix type, is becoming the focus of many studies. Traditional thought was that mixing waste as much as possible would optimize the exposure of the waste to the anaerobic bacteria, resulting in maximizing biogas production. However, current research is expanding the idea that minimally mixed waste results in a more stable digester, and in turn, greater biogas production. One such study was performed by Stroot *et al.,* in which identical digesters were operated at the same temperature and with the same influent, but with various loading and mixing levels. "The continuously mixed digesters exhibited unstable performance at the higher loading rates, while the minimally mixed digesters performed well for all loading rates evaluated." They also found that a continuously mixed digester that had become unstable was quickly corrected by reducing the mixing level (Stroot *et al.*, 2001).

2.10 Benefits Of Anaerobic Digesters

Individuals and homes in many parts of the world are already harnessing the power of anaerobic digestion, even in impoverished, rural areas. One such example can be found in the country of Nepal; Gautam, Baral, and heart (2009) summarized the benefits of anaerobic digestion there. The main focus of the article is to explain the several regimes of life in Nepal that are now better because of the use of biogas. The

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authors then use their collected information to propose the aspects of life where the use of biogas could be expanded. The article is a simple summary of biogas use in Nepal, so no methodology was employed except for basic fact finding. Besides some numerical data, the article is a qualitative analysis of biogas use. Despite its brevity, the article succeeds in showing how biogas has improved daily life in Nepal. The authors mention the effect of biogas on human health, hygiene, education, employment generation, gender benefits, economic benefits, and environmental benefits. The majority of these improvements center on rural households that utilize a fixed-dome-lagoon digester. Human waste and livestock waste are the primary sources of biomass for the digesters. The resulting biogas is then piped back into the households and connected to a stove where it is used for cooking, heating, and lighting. As a result of using biogas for cooking and heating, rural residents experience improved health from reduced smoke exposure indoors, reduced acute respiratory infections in populations of all ages, less infant mortalities, reduced vision ailments, and reduced concentrations of carbon monoxide, formaldehyde and suspended particles indoors. Gautam, *et al*., estimate 77,000 families in rural Nepal have a digester directly connected to their toilet. This simple connection has helped greatly reduce the issue of human waste management in rural areas, especially where no waste management systems are installed. In turn, anaerobic digesters are a great help in minimizing contagious diseases from human excreta such as diarrhea, cholera, and tuberculosis. Improvements in education are evident by the simple means of light from biogas. Most of Nepal lacks any electrical power supply, so the "establishment of biogas digesters has provided energy for lighting in more than 20,000 households in rural areas. This has provided a convenient means for reading or study even in the dark." In terms of

employment, the authors claim 11,000 people are employed directly because of anaerobic digesters, and another 65,000 from "the spin-off effect of employment in the biogas sector." Due to the established gender roles in Nepal, women have greatly benefitted from biogas. Because biogas is burned instead of firewood, females no longer spend time gathering firewood. Gautam, *et al*., claim a quantified benefit of 35,000 woman hours are saved a year due to anaerobic digesters. Also, biogas does not leave soot on cooking pots like firewood does, so less time is spent cleaning cooking utensils. Economic and ecological benefits are viewed together in terms of the reduction of fuelwood consumption, reduction in the use of agriculture residues in stoves, reduction in the use of dried cattle dung in inefficient stoves, reduction in kerosene use, and reduction in chemical fertilizer use. After explaining these benefits, Gautam, *et al.,* culminate the article by showing that only 9% of the biogas potential is being utilized in Nepal, based on the number of livestock compared to the number of digesters currently installed. Based on the comparison only using livestock manure, this number is actually lower as human waste is discussed in the article, but not included in the authors' calculation. Either way, the authors show the great benefits of biogas in Nepal, despite such a small percentage of the potential being utilized. The authors also point to some minor challenges in increasing digester numbers: cold temperatures in Nepal, lack of private companies specializing in digesters, remote locations of many residents, and complaints of increased mosquito populations around installed digesters. However, the authors are basically calling for more digesters to be established in Nepal, based on the benefits seen by those utilizing biogas. Advanced nations may be beyond having lagoon digesters in the backyard of every household, but a huge potential for them is evident in developing

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countries that are struggling for established energy sources and waste management (Gautam, *et al*., 2009).

Anaerobic digesters are also finding strong support throughout China, as explained by Liu Yu, *et al.* (2008). Since the 1970s, the Chinese Government has been popularizing the use of household biogas digesters to meet rural energy needs. As a result, approximately 17 million households are currently using biogas rather than the traditional fuels of straw, fuelwood, coal, refined oil, electricity, liquefied petroleum gas (LPG), natural gas, and coal gas. The authors' intent was to show the impact of biogas by calculating the energy substituted by biogas, and the potential GHG emissions from the traditional fuels if biogas had not been utilized. Energy consumption was analyzed from 1991 to 2005, comparing all fuels for energy in tetrajoules (TJ) and GHG emissions in gigagrams (Gg) CO_2-eq. The energy calculation demonstrates how many TJs of energy were consumed from biogas production, and then inferring that is how much energy from traditional fuel was conserved. Once values for conserved, traditional fuels were determined, the authors calculated the GHG emissions not emitted since those traditional fuels were not consumed. Also included in the GHG emissions calculation was the amount of methane from manure that is now being captured in the digesters, and not released into the atmosphere. A quantitative approach was understandably used in this research. The validity of energy consumption data could be called into question, but the authors made legitimate calculations with the resources they had available. The results are very promising in respect to GHG emission reduction and the positive influence of anaerobic digesters in rural China. For the period of the study, biogas was credited with producing 832749.13 TJ of energy. Biogas combustion emitted 36372.75

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Gg CO_2-eq, much less than 73157.59 Gg CO_2-eq that would have been emitted from combustion of the traditional fuels. After incorporating the manure management, biogas was credited with GHG emission reductions of 84243.94 Gg CO_2, 3560.01 Gg CO_2-eq of CH_4, and 260.08 Gg CO_2-eq of N_2O. Based on the growth of anaerobic digesters in China, biogas production is estimated to reach 15.6 billion m^3 in 2010 and 38.5 billion m^3 in the year 2020. The resulting reductions of GHG emissions would be 28991.04 and 46794.90 Gg CO_2-eq, respectively. The article could be aimed at both academics and practitioners. The methodology needs to be reviewed by other academics for its applicability to other countries, and the practical side is more evidence for the global benefit of anaerobic digestion. The article also brings to light a need to examine China's method for such a vast distribution of anaerobic digesters, and the applicability of assisting struggling, third world countries with harnessing the potential of biogas (Yu and others, 2008).

2.11 Biomass Sources For Anaerobic Digesters

Another important development in biogas production, especially for farms, is including crops and crop residue in manure to be digested together. Lehtomaki, Huttunen, and Rintala (2007) analyzed the potential of various crops with manure for biogas. The focus of the work was to measure possible increases in biogas yields by adding grass silage, sugar beet tops, and oat straw with cow manure. The research was a quantified approach to determine any value to adding crops to the manure. The methodology is clear; the experiment measured a control batch of just manure, and then compared the findings to biogas yields of manure in combination with various percentages of the above-mentioned crops. All of the experiments were run in the same

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digester for continuity. A single farm was used as the source of manure to minimize the

variability of manure from one farm to another. The article appears to be written with

academics as the intended audience, which may be ironic because the applicable findings

of such work are most practical for farmers who operate their own anaerobic digesters.

Despite the scientific nature of the writing, the results were rather clear that a

combination of crops and manure created more methane than manure alone. A promising

aspect of these results is the idea that farmers could use crop residue/waste to increase

methane yields. So rather than using precious cash crops, farmers could turn commonly

ignored biomass like corn stalks into energy. The authors determined the best

combination of crops and manure to be 30% crops and 70% manure. At this ratio,

methane yields were increased by up to 65% compared to the control batch. Of the three

crops, sugar beet tops had the highest methane potential per volatile solids (VS). These

findings obviously lead to questioning how other crops would perform in combination

with manure. To the authors credit, experimenting with sugar beets and grass silage had

never been done before: "the present study is the first long-term co-digestion study

demonstrating that co-digestion of manure with sugar beet tops and grass is a feasible

manner of increasing volumetric methane production (by up to 65%)" (Lehtomaki, *et al*.,

2008).

2.12 Anaerobic Digesters For The Treatment Of Manure

Increasing in scale of biogas use, farms are great benefactors of anaerobic

digestion. Originally just used for manure and odor management, farms all over the

world are realizing the energy potential of large-scale digesters. Cantrell, *et al*. (2008),

summarize these benefits in their USDA work. The work is focused on educating

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farmers throughout the U.S. to understanding the potential that lies within the waste of their livestock. In other words, "the primary objective of this work is to present established and emerging energy conversion opportunities that can transform the treatment of livestock waste from a liability to a profit center." The work is a qualitative approach to explaining the various types of digesters, and which one may suit a certain farm the best. A solid explanation of anaerobic digestion specifically for manure is also presented. Showing the expansion of digesters in the U.S., the authors cite a doubling of installed digesters between the years of 2004-2006. As of April 2008, the EPA reports 114 operating, farm-scale digesters on commercial farms in the United States (U.S. EPA, 2008). The authors provide a simple breakdown of the various temperature classifications for anaerobic digestion. The three classes listed are: psychrophilic (4-20°C), mesophilic (20-45°C), and thermophilic (45-60°C). The higher the temperature of the digester, the higher the metabolic activity of the bacteria will be, thus enabling a higher yield of biogas. The authors also provide an expansive list of benefits for farmers using biogas: odor control, reduction of nuisance gas emissions, potential pathogen kill, reduction of wastewater strength (oxygen demand), conversion of organic nitrogen into plant available ammonia nitrogen, preservation of plant nutrients (e.g., N, P, K) for use as a high quality fertilizer, and production of a renewable energy source. In discussing digester technology, the authors mention a fourth type in addition to the basic types mentioned earlier. Fixed Film digesters are discussed as an option when dealing with manure with a very low solid content. Such manure is commonly found on dairy and swine farms that use water to collect and transport livestock waste. The resultant liquid is not suitable for typical digesters, but performs well in a fixed film digester. The fixed

film digester is a large holding tank with an inert media covering the inside of the tank. Anaerobic bacteria are then inoculated throughout the media and become "fixed" to the tank. Wastewater can then pass through the tank for relatively short periods of time (1-6 days as compared to 20-30 for the other digesters). The wastewater creates biogas quickly, but does not flush out the important bacteria because they are attached to the walls of the tank. Because the tank can be built vertically, fixed film digesters are also of great benefit to farms that are restricted in building space. This article presents a solid explanation of why farms should invest in anaerobic digester technology, and the fundamentals of biogas production to be explained by the common farmer (Cantrell, *et al*., 2008).

A very recent article that has contributed to bringing attention to biogas is Cuellar and Webber (2008) from the University of Texas. The title seems to direct the article towards those involved in agriculture, but the public in general could benefit from this work. The article comes along at a time of growing awareness of the dangers of greenhouse gas emissions and global climate change. The authors take a simple, quantified look at the ability of anaerobic digestion to reduce GHG emissions and create electricity in the U.S. The methodology is a basic equation to show the results of utilizing the manure of all livestock in the U.S to produce biogas. A few assumptions had to be made for such a sweeping concept: every animal unit produces the same amount of manure a year, an animal unit is equal to 1000 pounds of animal, and the animal unit total remains constant at 95 million throughout a single year. Using all livestock in the U.S. for biogas is obviously not a realistic endeavor, however the results definitely contribute to a larger wave of ideas to break the U.S.'s dependence on fossil fuels. According to the

authors' research, GHG emissions from the agricultural sector in the U.S. amounted to 536 million metric tons (MMT) of CO_2-eq (7% of total U.S. emissions in 2005). Up to 25% of these agricultural emissions are from manure alone. Based on the assumptions above, and averaged values for the BTU potential of each type of manure, the authors determined manure could produce 88 $x10^9$ kWh a year. This is only 2.4% of the nation's electricity consumption, but the true benefit is found in the reduction of GHG emissions. By comparing biogas emissions to the emissions from the utilized manure and offset coal consumption, the U. S. could reduce GHG emissions by 99 million metric tons. Although the results are promising, the authors are first to admit that future research is required before every farm in the U.S. invests in an anaerobic digester. Such issues as biogas processing and distribution need to be analyzed before the resource can be utilized in widespread fashion. Although converting manure to biogas could make substantial positive contributions in reducing GHG emissions, further examination of policy, regulatory, and economic barriers must be examined before widespread implementation of biogas utilization. (Cuellar and Webber, 2008).

2.13 Anaerobic Digesters For The Treatment Of Municipal Solid Waste

Forster-Carneiro, *et al.,* (2008) have performed important experiments focused on inoculum sources for digesting municipal waste. In essence, solid waste will decompose faster and produce more biogas if it is mixed with other material that will also decompose, especially if that material already contains anaerobic material. Their primary study tested six substances mixed with organic waste from a university restaurant: corn silage, rice hulls, cattle excrement, swine excrement, digested sludge, and swine excrement mixed with digested sludge at a 1:1 ratio. The digester was operated at 55º C,

focusing on an optimum temperature for thermophilic bacteria. Despite previously

discussed percentages for total solids in waste for digestion, the scientists mixed their

waste to 30% total solids. Results were taken from 0-60 days for biogas production and

methane composition. For both before and after 60 days, digested sludge proved to be

the greatest producer of biogas and methane composition. The sludge inoculated waste

also showed the greatest reductions in volatile solids and chemical oxygen demand.

Cattle manure proved to be the worst inoculum for municipal waste despite its known

potential as a biogas producer on its own (Forster-Carneiro, *et al*., 2008.)

2.14 Conditions For Anaerobic Digestion

Several conditions within a digester influence the production and capture of

biogas. The most important issues that arise in the current research are temperature and

pH. Maintaining a constant temperature is key throughout the digestion process due to

the sensitivity and activity of anaerobic bacteria. A simple classification of anaerobic

bacteria is based on temperature, namely mesophilic and thermophilic bacteria.

Mesophilic bacteria thrive in temperatures between 30º C and 38º C; thermophilic

bacteria prefer 44º C to 57º C. Increased temperature leads to increased activity within

the digester, which typically results in greater biogas production. However, the increased

activity can also result in the unstable conditions mentioned previously. Several studies

have focused on determining the optimal temperature for digestion; mostly all result in

concluding the finding of a specific temperature for a specific influent composition. In

other words, different organic materials can have different optimal temperatures for

decay. A range between 25º C and 35º C has been accepted by many as the preferred

option due to stability, biogas production, and less cost compared to heating a digester for

thermophilic activity. Thermophilic bacteria have also shown greater sensitivity than

mesophilic bacteria to changes in temperature, in some cases even a 1º C change resulting

in a digester becoming unstable (Igoni *et al.*, 2008). Castillo *et al.,* concluded that 38-40º

C was the optimal range to digest the biodegradable fraction of urban solid wastes (USW)

in developing countries. Although their experiment was limited to a 20 L batch digester,

the thermophilic bacteria produced more biogas and decomposed the influent better than

the mesophilic bacteria. This finding points to using thermophilic conditions if heating

the digester is not an issue and the bacteria are maintained in a stable condition.

However, these results may not be attainable in a digester sized to handle a realistic load

of waste, such as a city's wastewater treatment plant for example (Castillo *et al.*, 2006).

Another variable that Castillo's group examined, along with many other studies, is the

optimal pH for anaerobic digestion.

   Castillo, *et al*., (2006) found that a neutral pH very near 7 was the optimal level

for digestion. There is little coincidence that this pH range happens to be the optimal

range for anaerobic bacteria in general. These studies also found that the digester

systems are predominately self-stabilizing in regards to pH. The initial phase of

anaerobic digestion produces volatile fatty acids that lower the pH of the system, but

reactions of carbon dioxide and hydroxide ions result in bicarbonate ions before the pH

becomes too low. In turn, the system is buffered well and can handle the increased

amounts of acid. Sufficient alkalinity has to be continually available, up to a level of

approximately 3000 mg/L, for sufficient buffering to be maintained, to ensure a high rate

of methane production. As in many wastewater treatment plants, lime can be used to

help raise the pH of a system that has dropped too low. However, excess lime results in

the precipitation of calcium carbonate and will hamper the production of biogas. Lately, sodium bicarbonate has become the agent of choice to raise pH due to a lesser fallout of precipitate. Another influence of pH is that the hydrogen-ion concentration is directly related to microbial growth in the system. Too low of a pH results in a system too acidic for the bacteria to grow, resulting in an unproductive digester (Castillo, *et al*., 2006).

2.15 Spark-Ignition And Compression-Ignition Engines Operated On Biogas

Biogas is capable of creating electricity when combusted in an engine/generator unit. Tippayawong, Promwungkwa, and Rerkkriangkrai (2007) present important findings on using biogas in generators. The main focus of the work was to compare a typical diesel generator to a generator utilizing biogas. A combined qualitative and quantitative approach was used in the research by running an engine of each type side-by-side. Engine specifications and qualitative descriptions were then recorded for each engine. Assuming an understanding of the benefits of anaerobic digestion, the authors strive to show that biogas is not a poor substitute for diesel fuel, and in fact, is very comparable. The engine used was a Mitsubishi DI-800 connected to a 5.0 kW, 220 V generator. The DI-800 is a single-cylinder, four-stroke, compression ignition engine that runs on diesel fuel. A second DI-800 was altered to run on biogas with an addition of diesel to act as a pilot. Engine performance was studied for each over a continuous, 50 hr experiment and then compared. The biogas engine was then run for 2000 hours to study long-term effects of burning biogas instead of diesel. The authors' explanation of the experiment is easy to understand and raises few, if any, questions as to the scientific

validity of the experiment. The results of the experiment were very promising for substituting diesel with biogas. A 90/10 biogas to diesel mix was able to run the engine for 2000 hours, showing a 7% increase in power output over the diesel-only version. After 2000 hours of use, the biogas model engine showed no lack in performance, or any signs of adverse wear. Small carbon deposits began to form on the biogas engine parts, but were corrected with simple maintenance and cleaning. The authors did fail to discuss the resources/cost to modify an engine to run on biogas, which could be a major drawback for many of those interested in utilizing such technology. However, the potential for utilizing biogas is evident, and a strong likelihood exists that engine makers and engineers will make biogas-capable engines readily available in the future. Once biogas engines are available at a reasonable cost, "adoption of this technology will boost proportion of the farms' renewable energy usage and reduce diesel fuel cost" (Tippayawong, *et al*., 2007).

Converting biogas into a fuel capable of running a spark ignition (SI) engine could have a huge impact on the general public; Shrestha and Narayanan (2008) examine this topic. The research was motivated by rising oil prices and an increasing interest in breaking our country's dependence on fossil fuels. The article is primarily directed towards the mechanical engineering field; the authors are very explicit in describing the engine, fuel control, and fuel mixtures used in their experiment. They use a quantitative approach to compare the power output of a single-cylinder engine when fueled by pure methane, biogas, and biogas with an addition of hydrogen. Although the specifics of the article analyze such topics as spark-ignition timing and adjusting compression ratios, the overwhelming theme is that SI engines can be run completely on biogas. Unfortunately,

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the authors did not run any trials of their engine with gasoline. Comparing biogas to regular, unleaded gasoline would provide the general public with a simple ratio to comprehend the potential of biogas. Within the context of the experiment, the authors were able to achieve similar engine performance with biogas as they achieved with methane. The promising results of biogas with hydrogen showed a 12% increase in power output and 15% increase in engine efficiency. "Additions of hydrogen also improved the combustion characteristics and reduced cyclic variations of landfill gas operations." Although the experiment utilized a single-cylinder engine, one can easily imagine the potential of running a four or six cylinder engine as well. In turn, future automobiles could operate with pure biogas, or a biogas/hydrogen blend (Shrestha and Narayanan, 2008).

2.16 Economic Feasibility of Anaerobic Digestion To Produce Electricity on Florida Dairy Farms

Giesy, *et al.*, (2005) performed a digester feasibility study for three dairy farms in Florida. Although the study was solely for dairy farms utilizing cow manure for biogas production, the approach used is very applicable to this thesis. Several assumptions were made to accomplish the study in a simple manner. The researchers focused on fixed-film and lagoon designs for the digester, as these two are the most suitable for cow manure. Capital costs were specific to each farm based on the number of cows and current infrastructure; the range was from $452 to $1,173 per cow. Operating and maintenance (O&M) costs were set at 2% of the determined capital costs. The discount rate, or opportunity cost of capital, was varied between 0-10%, with the control value set at 8%. The retail value of electricity was $0.10 per kWh. All wastewater produced on the farm

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was presumed to be used in the digesters. The digesters were given a 10-year life

expectancy with a $0 salvage value. The feasibility analysis was performed using a net

present value (NPV) calculation, the sum of net expected cash flow values adjusted to

current dollars. If an alternative was found to have a positive NPV, that option was

deemed more profitable than the control option (which generated a return on investment

equal to the discount rate of 8%.) The authors also discuss a few limitations in their

calculations that deserve note. As noted above, all wastewater was presumed to be

processed by the digester. If only the manure were to be processed through the digester

by a pre-screening process, rather than all of the wastewater, digester size, and thus

capital costs, would be reduced. Also, there are benefits of a digester that did not

currently have a numeric value. For example, a properly functioning digester can reduce

or eliminate odors that otherwise would be present in the decomposition of manure in an

open environment. A digester would reduce GHG emissions as well, which would

contribute to tax credits and/or trading carbon credits. However, these qualities did not

have exact values at the time of this analysis. The digesters were also analyzed with an

underestimated-efficiency of 25% conversion of biogas to electricity. Overall results

showed that an anaerobic digester installed at a discount rate of 8% would prove to be

profitable if electricity costs were $0.12 per kWh or higher (Giesy, *et al.*, 2005).

2.17 Wright Patterson Wastewater Treatment Plant Study

In 1989, consulting engineers Shaw, Weiss, and De Naples of Dayton, OH

analyzed alternatives for the treatment of wastewater from WPAFB. Three primary

alternatives were initially considered: construct a treatment facility on base to treat all

effluent from WPAFB, divert all effluent from WPAFB Areas A, C, and Woodland Hills

to the wastewater treatment plant in Fairborn, OH, or continue to discharge effluent to Dayton's wastewater treatment plant (status quo option). The Fairborn option was quickly ruled-out as the facilities there were inadequate to handle the waste stream from WPAFB. Various possibilities for a new treatment plant were waned to the idea of building a complete treatment facility on Area B in order to treat all of WPAFB's wastewater. A quantitative analysis was performed for a plant on Area B versus the status quo option. The status quo option was deemed the better of the two due to expected costs for increased discharge-treatment requirements stemming from a new treatment facility. In turn, the status quo option was chosen by the command of WPAFB and no treatment facility was constructed. Despite these results, two important points from the analysis directly apply to this research: Area B has the infrastructure and space required to build a wastewater treatment plant and the cost analysis did not incorporate any energy benefits from the prospective treatment plant. Because WPAFB has the adequate space and infrastructure for an entire wastewater treatment facility, the same holds true for an anaerobic digester. Also, because an anaerobic digester would provide a renewable source of energy, installing a digester is a viable option that should be compared against the status quo of continuing to discharge to the Dayton wastewater treatment facility (Shaw, *et al.*, 1989).

III. Methodology

3.0 Required Information

Per the guidance of 10 CFR 436, and the additional variables asserted by this thesis, the following information was required for performing a cost analysis of an anaerobic digester: military base information, to include waste stream composition, volume, and sewage costs, energy consumption and costs, projected future sewage and energy costs, infrastructure requirements, principal investment costs of a prospective digester, operation and maintenance costs of a prospective digester, salvage value of a projected digester, projected performance of a prospective digester or performance of similar digesters in the local area, projected discount and inflation rates, and the appropriate single and uniform present worth multipliers based upon the determined rates and project life expectancy. The required information was then incorporated into a present worth calculation to be explained later in this section.

3.1 Base Information

The initial step for analyzing the potential of installing an anaerobic digester on a military base was to gather background information on the location in question. More specifically, data was obtained for the base's population, generalized activities of tenants, waste stream composition, waste stream volume, sewage costs, energy consumption, energy costs, projected sewage and energy costs in the future, and the cost of topsoil. As directed in 10 CFR 436.17, future utility costs can be projected from current costs using projected inflation rates, or acquired from the actual utility companies' projections. For the case of WPAFB, information was acquired from the 88th Air Base Wing Public

Affairs Department, the 88th Civil Engineer Directorate (88th CED), the Dayton Power and Light Company (DP&L), and the consultation report by Shaw, *et al.,* A base's population will directly affect the amount of wastewater output, as well as indicate how many people stand to benefit from renewable energy sources. The activities of the tenant units will affect the composition of the base's waste stream. Industrial activities can lead to higher metal and solid contents in the waste stream, resulting in poorer digester performance; whereas administrative activities will be similar to domestic wastewater compositions. Shaw, *et al.,* analyzed the composition of WPAFB's waste stream and their findings were used for this study. Perhaps the most important piece of information is the actual volume of wastewater output from the base, as this provides the primary biomass for the digester. A mass-balance view of a digester will show the importance of the amount of biomass available, as the system can only output energy equal to that of what is put into it. This is of course for a system that is 100% efficient. Digesters are not 100% efficient. However, wastewater does have potential energy that is usually wasted by being sent away to a wastewater treatment plant, rather than being harnessed on base. In turn, any energy gathered from an anaerobic digester on base could be seen as a benefit. In order to validate this benefit, the potential energy of the digester was compared to how a base currently acquires electricity and the associated cost, as well as a digester's contribution to the goals of EO 13423.

Another important aspect of base information is to analyze the wastewater infrastructure. The wastewater must ultimately be funneled into the digester for the digester to function, so a centralized collection point must exist or be created. If the current wastewater infrastructure is not conducive to a centralized collection point, a

completely separate analysis would be necessary to determine the feasibility and cost of altering the system, or building a new transport system to funnel the waste to the digester. If found to be necessary, this infrastructure cost would be added to the principal investment in the overall cost analysis. For the case of WPAFB, Shaw, *et al.,* determined the current infrastructure was conducive to a central discharge point in Area B, so this thesis will assume the same holds true for a central collection point. In turn, no infrastructure costs were added to the investment costs for the WPAFB example.

Current digesters operate better on sludge rather than typical, domestic wastewater, so a condenser or solids collection point would also benefit a potential digester operation. As a result, a base must have a minimum amount of free space to install a digester, as well as a possible condenser or solids collection point. The space required is determined by the specifications of the builder of the projected digester to be used. In the case of WPAFB, Shaw, *et al.,* determined Area B had enough land to construct a wastewater treatment plant (1000 m^2), so this thesis assumed there is ample space for a digester and any other required equipment. If a base does not have the required space, and the opportunity exists to acquire land to meet the requirement, the land acquisition cost should be added to the principal investment in the overall cost analysis.

The effluent of an anaerobic digester is similar to compost, and as a result, can be used for topsoil/landscaping purposes. Potential volume of effluent can be found by multiplying the base's waste stream volume by the prospective digester's specs for effluent volume per input, or multiplying the base's waste stream volume by the average effluent volume of local digesters divided by the average waste stream volume of local

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digesters. The WPAFB potential was found by using known influent and effluent volumes at the Dayton plant. The cost for compost-topsoil was determined using advertised prices of local vendors.

3.2 Prospective Digester Information

Regarding information on prospective digesters, data was obtained for capital investment costs, operation and maintenance costs, salvage value, life expectancy, and expected performance. These costs can come from a prospective builder/supplier, be projected from completed projects in the area, or be estimated using various computer programs as used by a base's civil engineers. The estimates for WPAFB came from recent projects at the Akron, OH WWTP and the Ohio State Agricultural Research and Development Center (OARDC).

3.3 Projected Discount and Inflation Rates

Projected discount and inflation rates for all cash-flow series calculations came from the most current Economic Report of the President's Council of Economic Advisors, as directed by 10 CFR 436.14. Rates used for the WPAFB study were found on p.54 of the 2009 Economic Advisors Report to the President (USCCEA, 2009). The adjusted interest rate used for all calculations was the discount rate (10 year treasury notes) minus the inflation rate (consumer price index).

$$i_{eff} = i_{discount} - i_{inflation} \hspace{3cm} \text{Equation 1}$$

3.4 Present Worth Multipliers

The present worth multipliers can be found in any engineering economic interest tables for the appropriate rates, as determined in section 3.3, and time period of the study. If the adjusted interest rate did not result in a discrete value, other options would have been to calculate the present worth values using the longhand equations for present worth, or using the present value functions found in Microsoft Excel.

3.5 Energy Potential And Savings

In order to estimate any potential energy savings from a prospective digester, a base command must know the potential energy benefits of its base's waste stream. A simple ratio using the known inputs and outputs of local projects suffices. Information on local digesters' input (MG/yr) and output (kW/yr) was obtained. A ratio was then set for the local digester data to equal the ratio of a base's unknown potential output over its known input:

$$\frac{Output_{local\ digesters}}{Input_{local\ digesters}} = \frac{X\ Output_{base}}{Input_{base}} \qquad \textbf{Equation 2}$$

The estimate for the energy potential of WPAFB came from operating digesters at the Dayton, OH WWTP and Akron, OH WWTP. The WPAFB estimate was determined by a simple ratio of the average energy output and average waste input of the above plants:

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$$\left(P_{Dayton} + P_{Akron}\right) \Big/ \left(I_{Dayton} + I_{Akron}\right) = P_{WPAFB} \Big/ I_{WPAFB}$$

<div align="right">**Equation 3**</div>

where:

P = Energy output (kW/yr)

I = Waste input (MG/yr)

The above ratio was then rearranged to solve for the WPAFB energy potential in kW/yr:

$$P_{WPAFB} = I_{WPAFB} * \left(P_{Dayton} + P_{Akron}\right) \Big/ \left(I_{Dayton} + I_{Akron}\right)$$

<div align="right">**Equation 4**</div>

This thesis asserts that the estimated energy production would result in that amount of energy not needing to be purchased from the local electric company. In turn, that amount of energy multiplied by the current cost of energy was considered energy savings. In the case of WPAFB, all energy is purchased from DP&L. Less energy purchased from off base would also result in less GHG emissions attributed to the energy consumed on base, as the fossil fuel-derived energy consumed on base would decrease, assuming that the local power company is burning a fossil fuel to create electricity. For 2010, the Dayton Power and Light Company projects the sources of its electricity production to be 89% coal, 1% natural gas and oil, and 10% unknown (DP&L, 2010). In turn, at least 89% of the energy purchased by Wright Patterson in 2010 will be derived from fossil fuels.

3.6 Financial Analysis

The overall financial analysis was a present worth calculation involving all variables discussed to this point, with the established assumptions found in section 2.5. In accordance with 10 CFR 436.18, a net savings analyses was performed. A resulting positive value would indicate a project that was worthy of acceptance. A negative value would indicate a project that did not make fiscal sense, and would require alternatives and/or improvements to one or more variables. The following is the cost analysis equation used for a proposed anaerobic digester:

$$PW = -C + (-O - M + E + S + T)(P/A, i, n) + V(P/F, i, n) + G$$

<div align="right">Equation 5</div>

Where:

PW = present worth ($)
P/A = engineering economics value to find PW given an annuity, based on i and n
P/F = engineering economics value to find PW given a one-time, future value, based on i and n
$i = i_{eff}$ Equation 1
n = expected life span of new digester (years) or 25 years, whichever is less
C = Capital and Installation Costs ($) = one-time expense paid at time = 0
O = Annual Operating Costs ($/yr) = average operating costs of local digesters
M = Annual Maintenance Costs ($/yr) = average maintenance costs of local digesters
E = Annual Electricity Savings ($/yr) = $P_{base}(kW/yr) * Cost_{base\ energy}($/kW)$ Equation 6
S = Annual Sewage Savings ($/yr) = $I_{consumed\ by\ digester}(MG/yr) * Cost_{base\ sewage}($/MG)$ Equation 7
T = Annual Effluent Value ($/yr) = $I_{base} * \dfrac{Effluent_{local\ digesters}(yd^3/yr)}{I_{local\ digesters}} * Cost_{topsoil}($/yd^3)$

<div align="right">Equation 8</div>

V = Salvage Value of equipment at the end of the study period
G = Grants awarded

4.0 Overview

This chapter presents the obtained data and calculations, in accordance with chapter 3, for the example of WPAFB. The following analysis is specifically for the case of WPAFB in order to provide an example of the proposed methodology. Whereas the proposed methodology is for any DoD installation, the following results are only for WPAFB and should not be applied to other locations.

4.1 Base Information

WPAFB is located in Dayton, OH and supports a workforce of over 25,000 military, civilian, and contract employees. The base is host to a diverse set of tenants and activities including the Air Force Material Command, the Aeronautical Systems Center, the Air Force Research Laboratory, the 445th Airlift Wing, the National Air & Space Intelligence Center, the Air Force Institute of Technology, the National Museum of the United States Air Force, the Air Force Security Assistance Center, the 88th Air Base Wing, the Wright-Patterson Medical Center, and the 554th Electronic Systems Group (88th ABWPA, 2010).

These tenants currently combine to create a waste stream of just over 3 MGD, with approximately 96% of this flow discharging to the Dayton WWTP and 4% discharging to the WWTP in the city of Fairborn, OH. For simplicity, this study assumed a 3 MGD flow to the Dayton WWTP due to the vast majority of wastewater being sent to Dayton in comparison to Fairborn. Shaw *et al.,* presented the volume and composition of the WPAFB waste stream by using a comprehensive report completed by the Air Force

Occupational Environmental Health Laboratory (OEHL) in 1978. The report still
remains as the most recent, definitive study of the composition of the WPAFB waste
stream. The volume has been updated by quarterly readings by the City of Dayton and
the 88th CED. The composition was determined to be similar to domestic wastewater,
enabling a direct comparison of WPAFB's digester potential to digesters in the Ohio area
operating on domestic wastewater. The specific composition findings are presented in the
following tables:

Table 1

Characteristics Of Domestic Wastewater Discharges To The Collection System					
Of The City Of Dayton From WPAFB August 1978					
Parameter/Station	5	6	7	Combined mg/l	Combined lb/day
Chemical Oxygen Demand	96	319	400	293.5	6075
Biochemical Oxygen Demand 5	32	97	197	104.8	2170
Suspended Solids	36	138	127	116.7	2416
Total Phosphate	1.5	4.15	8.3	4.5	92.8
Surfactants	0.27	1.76	8.4	2.8	58.2
Ammonia Nitrogen as N	4.9	10.9	19.3	11.4	237
Total Nitrogen	5.5	14.4	21.1	14.1	291
Phenols (ug/l)	7.5	34	25	27	0.56
Flow (MGD)	0.465	1.523	0.497	2.485 (MGD)	2.485 (MGD)

The composition data leads to a finding of .01% total suspended solids (TSS) in
the WPAFB waste stream. In order to thicken the waste stream to 10% TSS for the
digester as recommended by Igoni, *et al.,* the 3 MGD flow would need to be scrubbed of
2,996,499 gallons of water a day. This resulted in an estimated 3,500 gallon/day waste

stream to the digester. Shaw *et al.,* also affirmed the possibility of constructing an entire

wastewater treatment plant on Area B of WPAFB. As mentioned previously, this thesis

will assert that an anaerobic digester and associated facilities would easily fit in the space

(1000 m^2) designated in the study. The infrastructure currently in place, as presented by

Shaw *et al.*, would be conducive to a central collection point for operating a digester. In

turn, no land or infrastructure costs were used in the principal investment cost for

WPAFB (Shaw *et al.*, 1989).

4.2 Prospective Digester Information

Three anaerobic digesters in the Ohio area were chosen to project estimates for a

digester at WPAFB: Dayton WWTP, Akron WWTP, and OARDC. The following data

were obtained for this study:

Table 2

	Dayton	Akron	OARDC (manure/food/MSW)
Input (G/D)	72000000	75000000	19382 Wet Tons/yr
Output (kW/h)	922	1200	485
Principal Investment ($)	x	7000000	3000000
Operating ($/yr)	x	210240	84972
Maintenance ($/yr)	x	210240	84972
Effluent (yd3/yr)	13518.52	x	4710
Salvage Value ($)	0	0	0
Life Expectancy (yrs)	25+	25	25

(City Of Dayton, 2010 and Quasar, 2010).

The digester at OARDC was put into operation in December 2009, providing present day values for principal, operating, and maintenance costs for a potential digester at WPAFB. The digester model at OARDC, the F550 built by Quasar Energy Group, is able to consume manure, organic food wastes, and organic municipal solid wastes. According to Quasar, the digester at OARDC has educational and informative enhancements not needed for basic digestion and energy production. A F550 built at WPAFB would thus cost $2.5M. The operating and maintenance costs at Akron and OARDC were quoted at $.02/kW/h. These costs did not include personnel salaries, so an additional amount was added to the WPAFB estimate for maintenance. Quasar recommends at least one fulltime operator to work the digester for at least 6 hours/day. For this study, two employees were assumed to be hired at the median wage for a wastewater treatment operator, as determined by the Bureau of Labor Statistics for the United States Department of Labor (DoL, 2010.) The digester tanks installed at the Dayton WWTP were installed long enough ago that the facility personnel had no financial data on them. Because the OARDC digester uses various wastes for influent, only the Dayton plant was used to estimate the effluent amount at WPAFB. Scrap metal values at the end of life expectancy were assumed negated by disassembly and removal charges, so salvage values were viewed as $0 (Henry, 2010).

4.3 Projected Discount and Inflation Rates

Using the latest Economic Report of the President's Council of Economic Advisors, the furthest projected discount and inflation rates were 5.1% and 2.1%, respectively. Therefore the effective interest rate used for the present worth calculations was 3.0% (USCCEA, 2009).

$$i_{eff} = i_{discount} - i_{inflatio} = 5.1\% - 2.1\% = 3.0\%$$

4.4 Present Worth Multipliers

The present worth multipliers were based on 3.0%, as determined in section 4.3. Annuity calculations were based on a 25-year study per the life expectancy of a new digester. The present worth multiplier for an annuity over a 25-year period at 3.0% is 17.413. Because the net salvage value was asserted at $0, and no other one-time costs were recognized for the WPAFB estimate, no one-time present worth multipliers were necessary.

4.5 Energy Potential And Savings

Because this study only incorporated municipal wastewater as the influent for a digester at WPAFB, the OARDC digester, which uses multiple types of influent, was not used for the WPAFB energy potential estimate. In turn, the OARDC digester was not used in equation 4 and results in the following estimate for WPAFB.

$$P_{WPAFB} = I_{WPAFB} * \frac{(P_{Dayton} + P_{Akron})}{(I_{Dayton} + I_{Akron})}$$

$$P_{WPAFB} = 3\ MG/d * \frac{(922\ kW/h + 1200\ kW/h)}{(72\ MG/d + 75\ MG/d)}$$

$$P_{WPAFB} = 43.3\ kW/h = 379361.6\ kW/yr$$

According to the 88th CED, WPAFB consumes 55 MW/day at a cost of $.05/kW from DP&L (Vehorn, 2009). With this cost of electricity and the estimated P_{WPAFB} energy potential, the following energy savings could be attained by installing a digester at WPAFB:

$$E = 379361.6 \ kW/yr * \$.05/kW = \$18968.08/yr \qquad \text{Equation 6}$$

4.6 Financial Analysis

$$PW = -C + (-O - M + E + S + T)(P/A, i, n) + V(P/F, i, n) + G$$

Equation 5

Where:

P/A, 3.0%, 25 = 17.413

P/F, 3.0%, 25 = .4776

i = 3.0%   Equation 1

n = 25 years

C = $2,500,000

O = $.02/kW * P_{WPAFB} = $.02/kW * 379361.63 kW/yr = $7587.23/yr

M = ($.02/kW * P_{WPAFB}) + (2 employees)

M = $7587.23/yr + (2 employees * $38,430/employee/yr) = $84447.23/yr

E = $18968.08/yr   Equation 6

S = 3501 G/d * 365 d/yr * $3/1000 G = $3833.60/yr   Equation 7

T = 3 MG/d * (13518.52 yd^3/yr / 72 MG/d) * $30/yd^3 topsoil = $16898.15/yr   Equation 8

V = $0

G = Ohio "green" energy credit grant = "green" project kW/ h * 1000 W/kW * 3 $/W/h
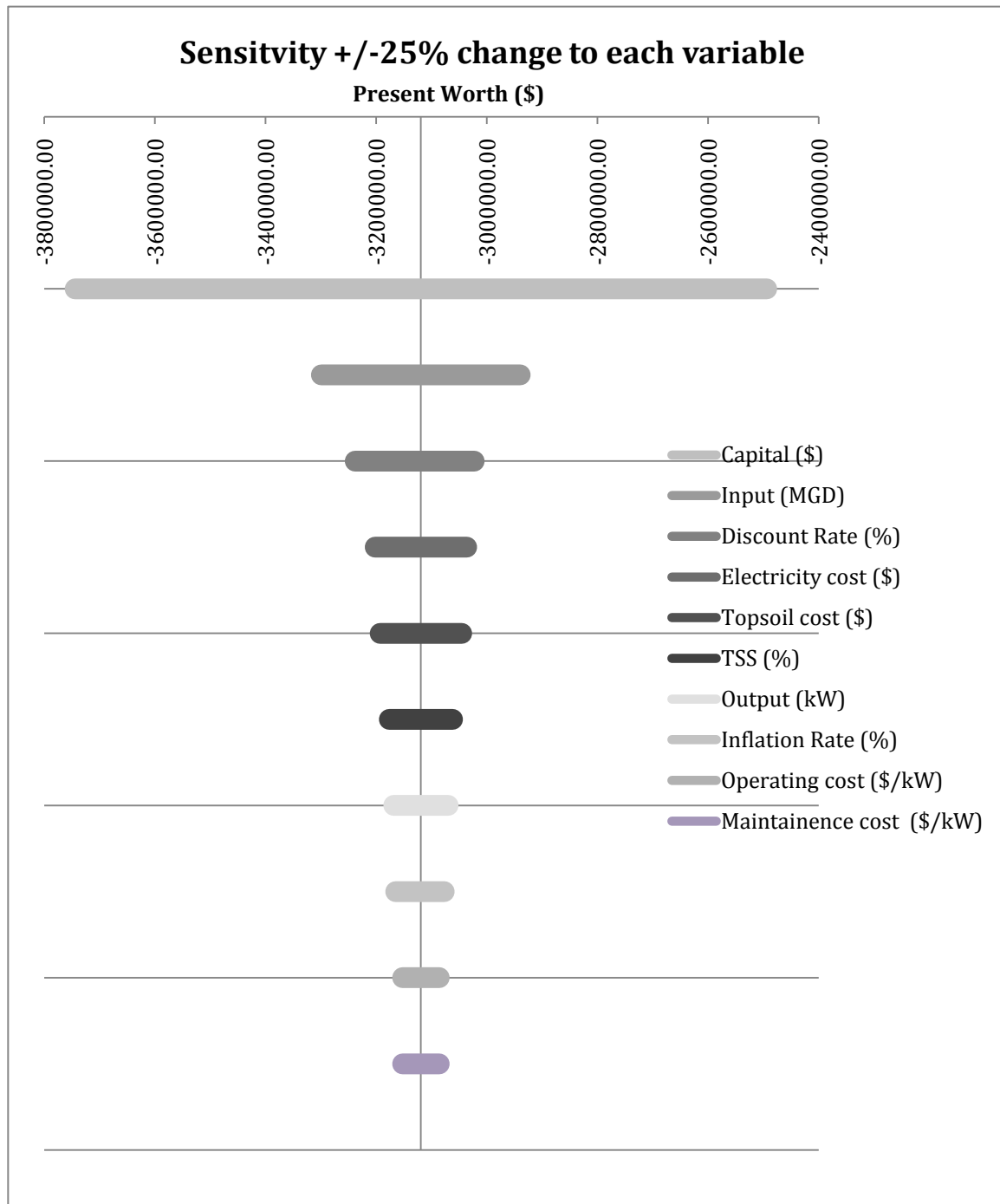
G = 43.3 kW/h * 1000 W/kW * 3 $/W/h = $129918.37

The resulting PW of Equation 5 for WPAFB equals -$3,281,392.46. This value

indicates that installing an anaerobic digester at WPAFB is not a fiscally sound decision.

In general, the financial benefits of a digester would never overcome the costs to install

and operate it, given the presented data. As a result, there is no length of time for this

digester to operate so that it would pay for itself.

4.7 Sensitivity Analysis

A sensitivity analysis was performed to demonstrate the influence of individual

variables on the overall cost estimate. The variables were adjusted +/- 25%, but the

present worth never resulted in a positive value. Adjusting the capital cost proved to

have the most influence on the present value. However, the annual costs were so much

greater than the annual benefits, that even if the capital cost was driven to $0, the present

worth was still -$781,392.46. The following tornado diagram shows the present worth in

regards to varying individual variables by +/- 25%:

Figure 1

Sensitvity +/-25% change to each variable

Present Worth ($)

Capital ($)
Input (MGD)
Discount Rate (%)
Electricity cost ($)
Topsoil cost ($)
TSS (%)
Output (kW)
Inflation Rate (%)
Operating cost ($/kW)
Maintainence cost ($/kW)

4.8 Digester Contribution To EPAct 2005 And EO 13423

Although an anaerobic digester on WPAFB would not pay for itself over a 25-year period, it would contribute a fraction of the electricity consumed on base. Based on the estimated digester performance of 1039 kW/d compared to the base's daily consumption of 55 MW/d, a digester would contribute 1.89% of the base's electricity supply. In accordance with the EPAct 2005, because this renewable energy would be created on the base, its contribution would count twofold towards the energy goals of the act. In turn, the 1.89% contribution would count as 3.78% towards the renewable energy goals of 5.0% for FY2010 and 7.5% for FY2013 (Holt and Glover, 2006). In regards to EO 13423, the 1.89% energy contribution could count towards the 3% annual energy reduction demand of goal (a) since the energy would no longer be coming from a fossil-fuel burning plant (DP&L burning 89% fossil fuel.) Goal (b) would be followed by the digester project being built on the base, however the present worth calculation raises the question of at what cost do federal agencies implement renewable energy products? The fulfillment of goal (c) would be assisted by a digester if the water from the digester could be recycled, however this would add to the capital costs for the extra equipment required to treat the water to discharging standards (Shaw, *et al.*, 1989). A digester would contribute 563 yd^3/yr of fertile compost in regards to goal (d), worth approximately $16898/yr. 3501 gallons/day of municipal solid waste would be diverted in accordance with goal (e) (Bush, 2007).

V. Conclusion

5.0 Conclusion

Given the current digester technology and costs, waste stream volume and composition, and projected benefits, an anaerobic digester does not make sense right now for WPAFB. Although a digester would contribute to fulfilling the requirements of EO 13423 and other associated acts, the benefits do not seem to validate the costs. The digesters operating in Akron and at the OARDC are fueled by waste streams with much greater biogas potential than the waste stream of WPAFB due to the percent of TSS. On the other hand, this study only considered wastewater for a digester influent, which in the case of WPAFB, is rather weak. Other organic material can be consumed in current digesters, as evident at OARDC and in several journal articles covered in section II. In turn, WPAFB could have a greater digester potential if organic waste were to be diverted to the digester. This study does not conclude that an anaerobic digester would not work at any other installation, only that the current conditions do not warrant a project at WPAFB.

Despite the negative findings in the present worth calculation for WPAFB, the equation itself can be applied to any other DoD installation. The demands of E.O. 13423, and the appearance of new technologies that would assist in executing this order, have highlighted the lack of guidance for performing a cost-analysis for such technologies. This study fills the void of guidance for analyzing anaerobic digesters.

5.1 Future Research

As mentioned previously, this study only considered wastewater as the influent for a digester at WPAFB. Further research of diverting other organic waste to a digester on base is required, both in regards to energy potential and infrastructure requirements. A more current analysis of the WPAFB waste stream is also needed, preferably over a 12-month period to incorporate weather, seasonal, and cultural changes. Actual testing of WPAFB wastewater in small-batch digesters would provide a more accurate value of power potential for the base. Future increases of personnel on WPAFB due to military relocations could also lead to greater energy potential. Because the goals of EO 13423 are inherently an order for the base, other means of renewable energy must be studied as well.

THESIS CALCULATIONS sensitivity.xlsx - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K
1		Dayton	Akron	OARDC (manure/food)	WPAFB	TSS PPM	TSS %	WPAFB Sewage Divert			
2	Input (G/D)	72000000	75000000	19382 Wet Tons/yr	3000000	116.7	0.01167	3501			
3	Output (kW/h)	922	1200	485	43.31			Dayton Sewage Cost ($/1000 gal)			
4	Principal Investment ($)	x	7000000	3000000	0			3			
5	Operating ($/yr)	x	210240	84972	7587.23	2 employees @ $38,430/y	Topsoil ($/yd3)				
6	Maintainence ($/yr)	x	210240	84972	7587.23	76860		30			
7	Effluent (yd3/yr)	13518.52	x	4710	563.27						
8	Salvage Value	0	0	0	0						
9											
10	WPAFB EXAMPLE	C	O	M	E ($/yr)	S ($/yr)	T	V	G ($ grant)		
11		0	7587.23	84447.23	18968.08	3833.60	16898.15	0.00	129918.37		
12									Ohio energy credit		
13	PW =	-781384.73							=$3/W		
14	discount	0.051			Water Scrub						
15	inflation	0.021			2996499						
16	i	0.03			WPAFB Electric Consumption (kW/yr)						
17	years	25			20075000						
18	Costs	($1,602,609.74)			Potential Digester Output (kW/yr)						
19	Gains	$821,217.28			379361.63						
20	difference	($781,392.46)			Digester Green Contribution %						
21					1.89		0.0189	3.7794			
22					Output (kW/yr)		Output (kW/d)				
23					379361.63		1039.3469				

	A	B	C	D
1		Dayton	Akron	OARDC (manure/food)
2	Input (G/D)	72000000	75000000	19382 Wet Tons/yr
3	Output (kW/h)	922	1200	485
4	Principal Investment ($)	x	7000000	3000000
5	Operating ($/yr)	x	=0.02*C3*24*365	=0.02*D3*24*365
6	Maintainence ($/yr)	x	=0.02*C3*24*365	=0.02*D3*24*365
7	Effluent (yd3/yr)	=45*2000/90/27*365	x	4710
8	Salvage Value	0	0	0
9				
10	WPAFB EXAMPLE	C	O	M
11		=E4	=E5	=E6+F6
12				
13	PW =			
14	discount	=0.051		
15	inflation	=0.021		
16	i	=B14-B15		
17	years	25		
18	Costs	=-B11+PV(B16,B17,C11,,0)+PV(B16,B17,D11,,0)		
19	Gains	=-(PV(B16,B17,E11,,0)+PV(B16,B17,F11,,0)+PV(B16,B17,G11,,0)-I11)		
20	difference	=B18+B19		
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				

	E	F	G	H	I	J	K
1	WPAFB	TSS PPM	TSS %	WPAFB Sewage Divert			
2	=3000000	116.7	=F2/10000	=(F2*8.34*(E2/1000000))/			
3	=E2*((B3+C3)/(B2+C2))			Dayton Sewage Cost ($/10			
4	0			=3			
5	=0.02*E3*24*365	2 employees @ $38,430/y		Topsoil ($/yd3)			
6	=0.02*E3*24*365	=2*38430		30			
7	=E2/B2*B7						
8	0						
9							
10	E ($/yr)	S ($/yr)	T	V	G ($ grant)		
11	=E23*0.05	=H2*365*H4/1000	=E7*H6	0	=E3*3000		
12					Ohio energy credit		
13					=$3/W		
14	Water Scrub						
15	=E2-H2						
16	WPAFB Electric Consumptio						
17	=55*1000*365						
18	Potential Digester Output (kV						
19	=E23						
20	Digester Green Contribution						
21	=E19/E17*100		=G23/55000	=E21*2			
22	Output (kW/yr)		Output (kW/d)				
23	=E3*24*365		=E3*24				
24							

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REPORT DOCUMENTATION PAGE

1. REPORT DATE *(DD-MM-YYYY)* 25-03-2010	2. REPORT TYPE Master's Thesis		3. DATES COVERED *(From – To)* Jun 2009-Mar 2010
4. TITLE AND SUBTITLE Economic Feasibility Of Installing An Anaerobic Digester On A Department Of Defense Installation		**5a. CONTRACT NUMBER**	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Strange, Russell A., Captain, USMC		**5d. PROJECT NUMBER** N/A	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way WPAFB OH 45433-7765		**8. PERFORMING ORGANIZATION REPORT NUMBER** AFIT/GES/ENV/10-M05	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Commandant of the Marine Corps (I&L) Environmental Section (LFL-6) Headquarters Marine Corps 2 Navy Annex Washington, D.C. 20077-5541		**10. SPONSOR/MONITOR'S ACRONYM(S)**	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	

12. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Improving technology has made anaerobic digestion a viable method for disposing of organic waste and creating alternative energy. The purpose of this research was to examine the feasibility of installing an anaerobic digester on a Department of Defense installation, and measure its contribution to the execution of Executive Order 13423. A present worth equation was derived in accordance with 10 Code of Federal Regulations 436 expressing viable costs and benefits of an anaerobic digester. A case study of Wright Patterson Air Force Base (WPAFB) was then presented using the derived equation and operational data from functional digesters in the Ohio area. The research identified that an anaerobic digester at WPAFB is not financially practical at this time, but would contribute towards the goals of Executive Order 13423. The derived cost-analysis equation can be applied to any U.S. military base.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18.NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Lt Col David A. Smith (AFIT/ENV)
a. REPORT U	**c. ABSTRACT** U	**c. THIS PAGE** U	UU	70	**19b. TELEPHONE NUMBER** *(Include area code)* 937-785-3636 ext. 4711